

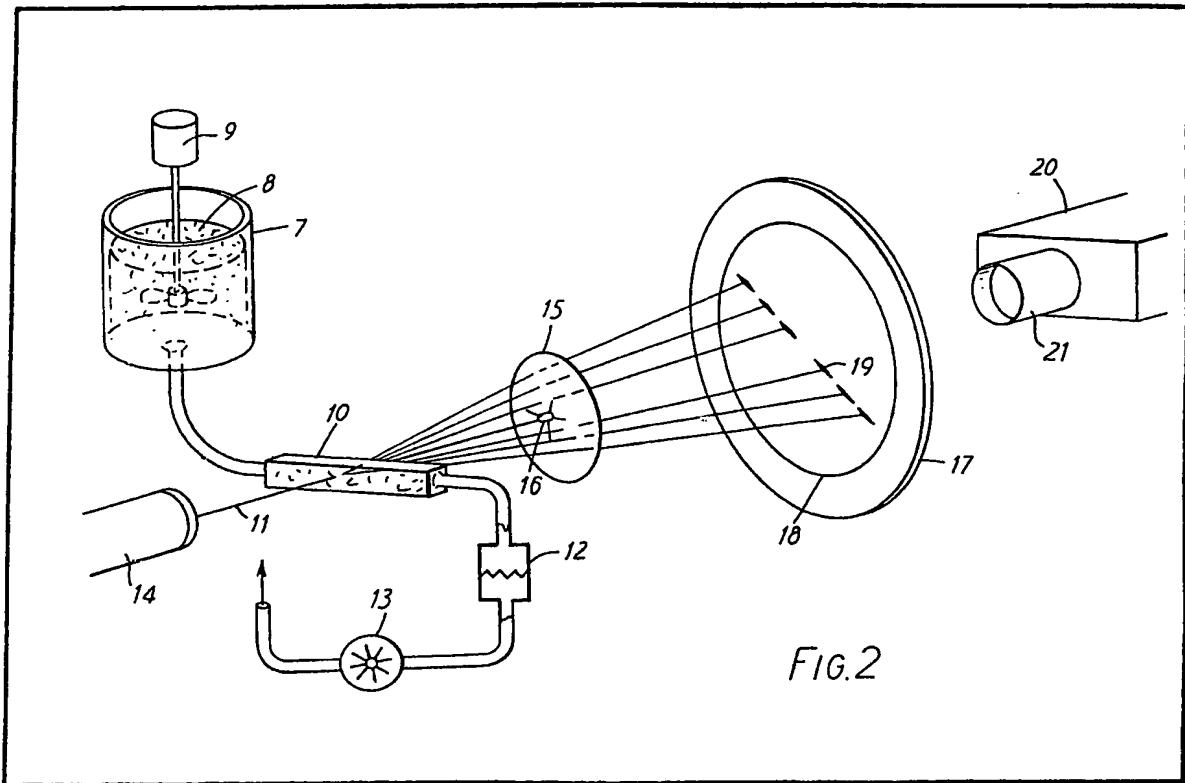
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## (54) Measurement of diameters of small objects

(57) Small objects such as snippets of textile fibre (i.e. dispersed in liquid 8) are conveyed across the path of a laser beam (11) to form a diffraction pattern (19) which is detected by an opto-electronic transducer (camera 21). Because of the fleeting nature of the image, the pattern is electronically stored to permit analysis for determining the diameter of the object. A hydrodynamic focalisation arrangement for the liquid (8) is also described, in which a second flow of liquid surrounds a first stream containing the objects, to effect a constriction of the first stream.



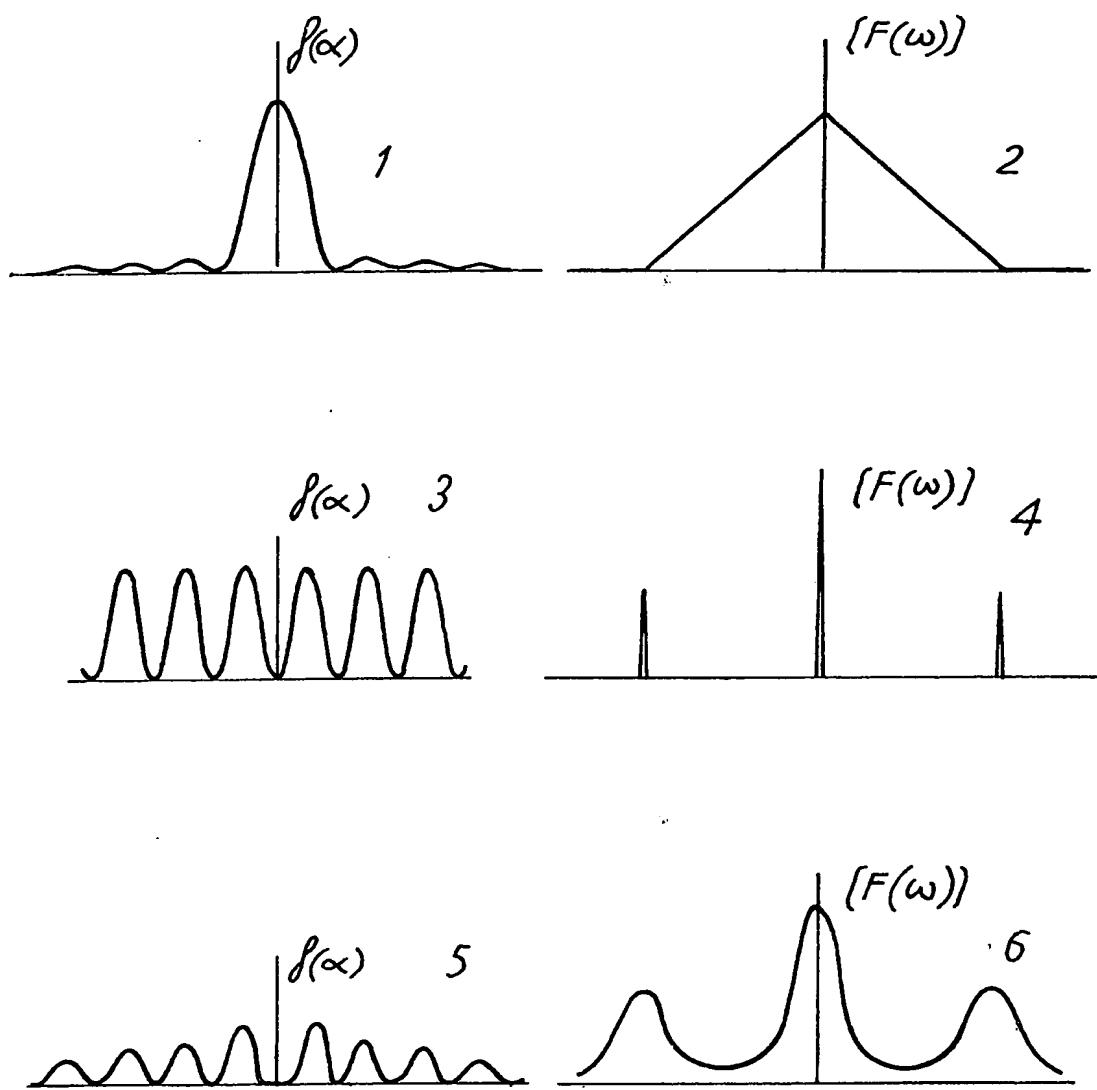
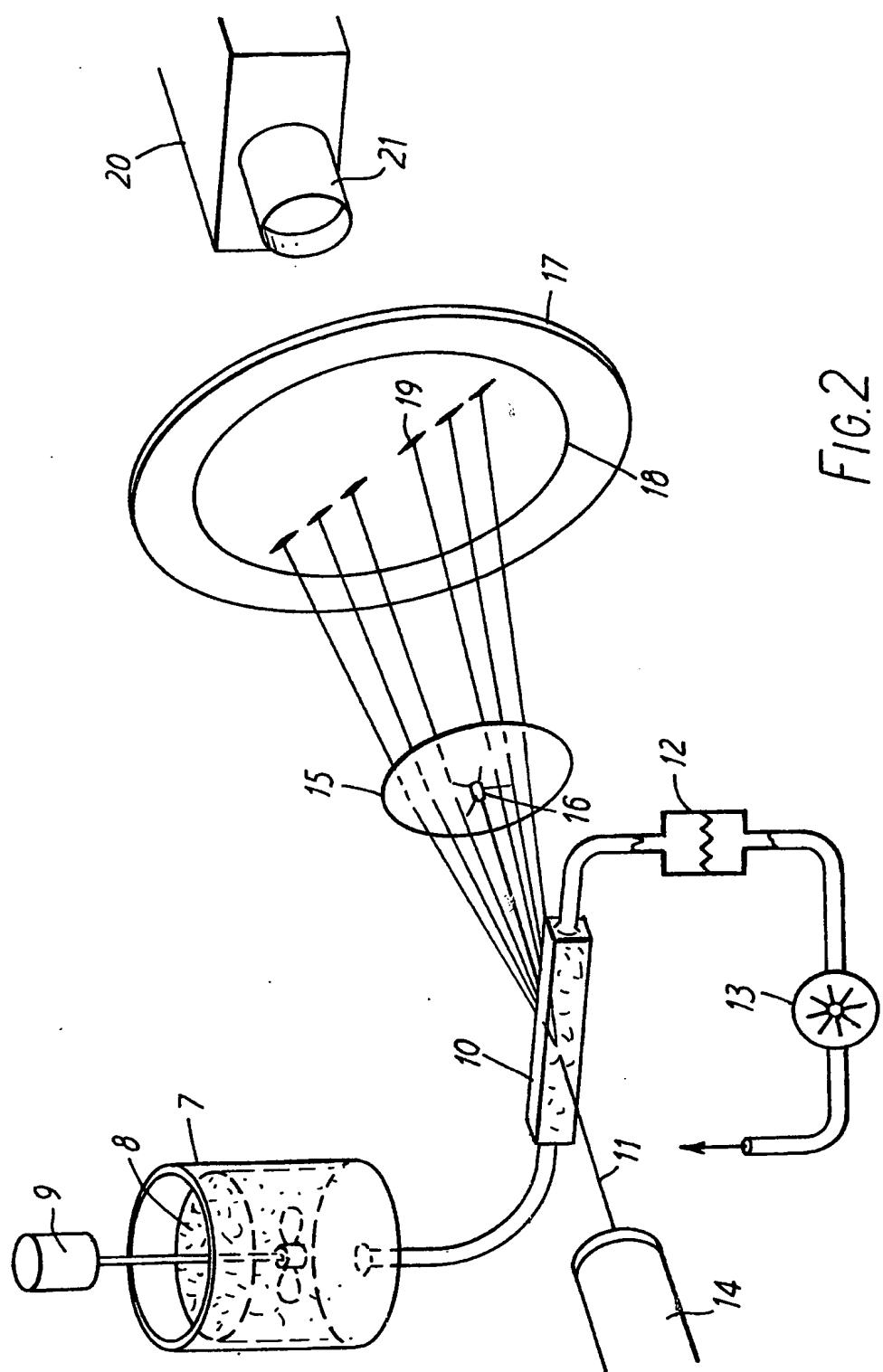


FIG. 1

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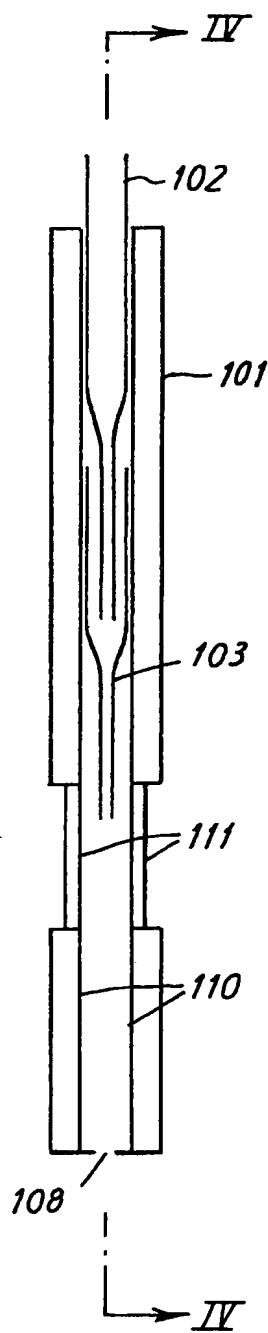


FIG. 3

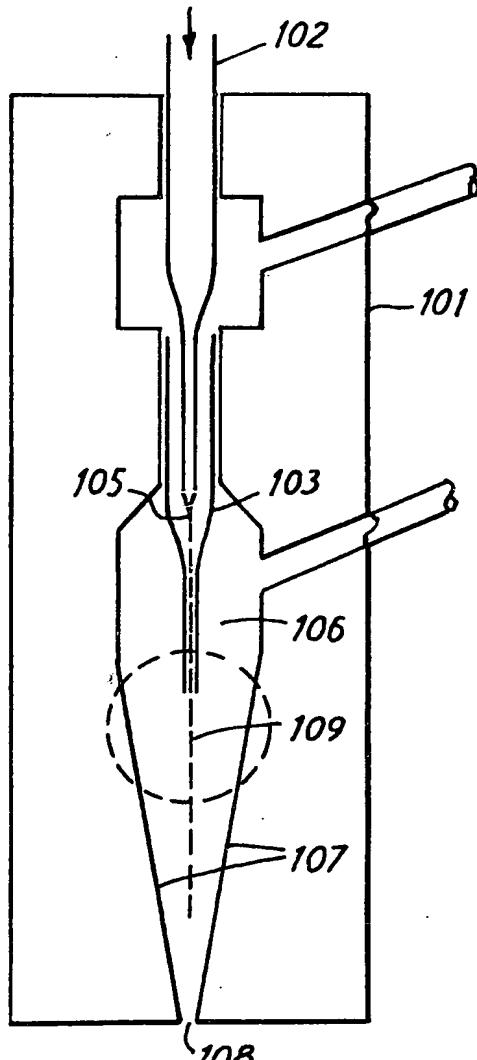


FIG. 4

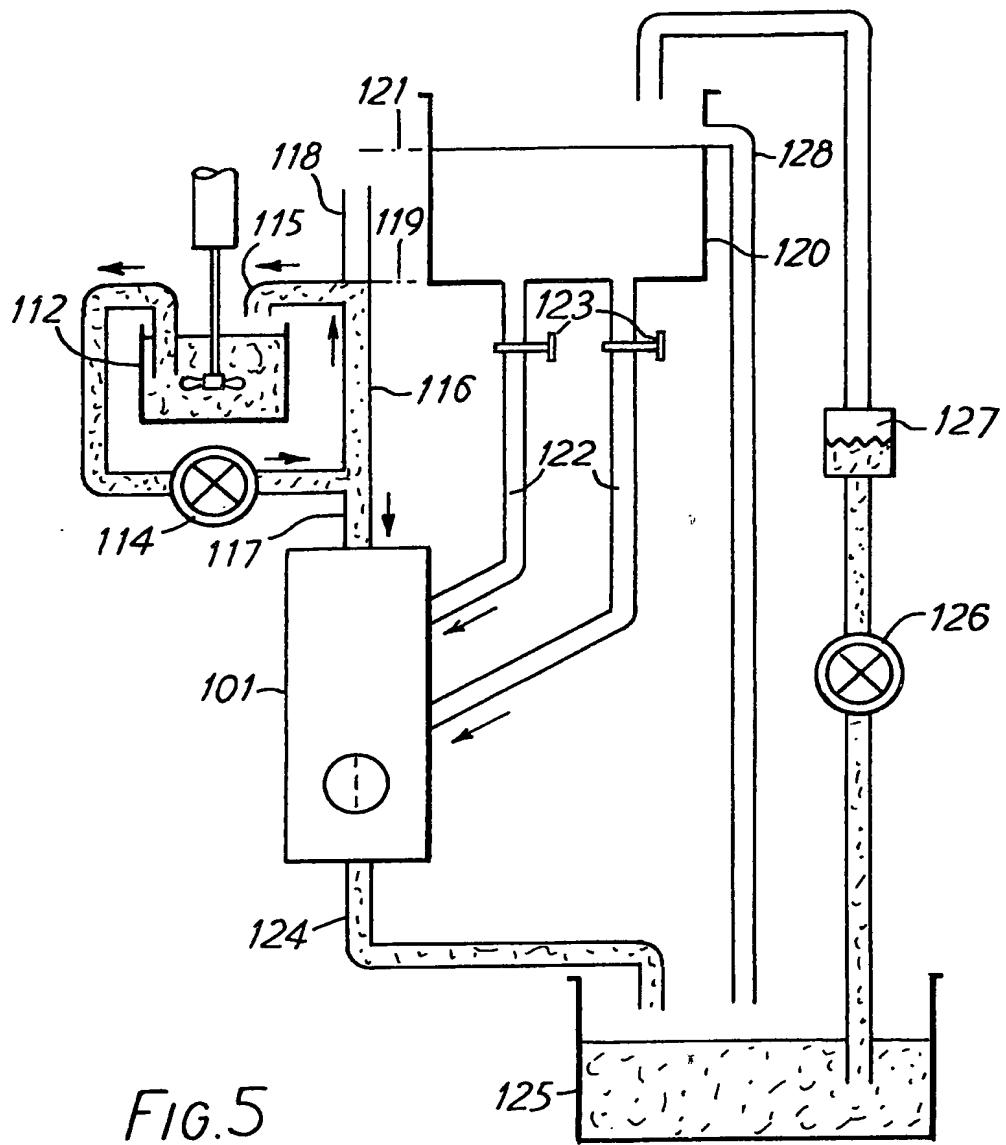


FIG. 5

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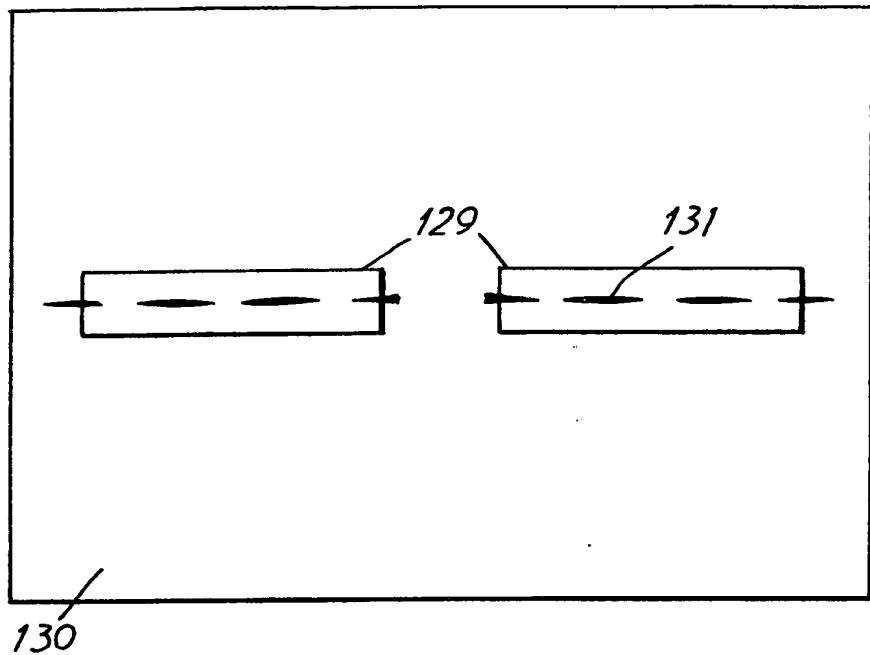


FIG.6

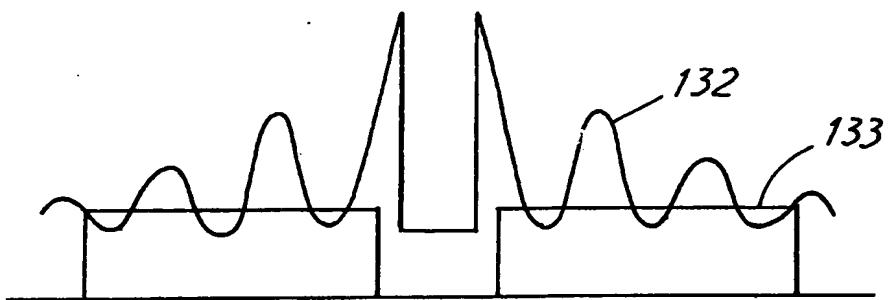


FIG.7

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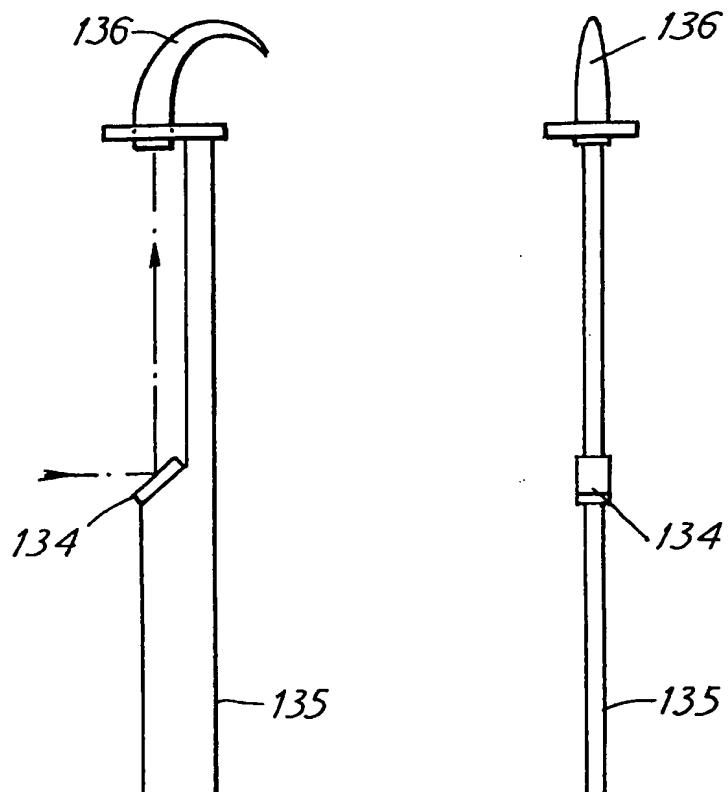


FIG. 8

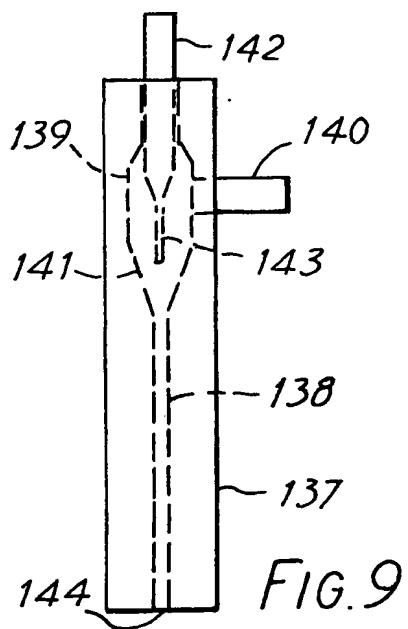


FIG. 9

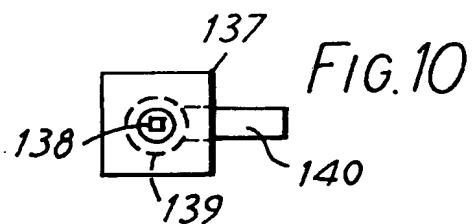


FIG. 10

**SPECIFICATION****Measurement of diameters of small objects**

The invention relates to the measurement of the diameter or thickness of small objects of substantially circular cross-section, more especially textile fibres or fine wires.

Since the early days of the industrial era, knowledge of the diameter of textile fibres has been recognized as a necessity, for this physical property has an important effect on textile processing and on ultimate fabric properties. In consequence, the price of fibres is highly dependent upon their dimensional characteristics. It is thus of prime importance to find a technique for objective fibre diameter measurement. Several systems have been developed that measure the mean diameter of fibre samples, but most suffer from various disadvantages. Some are tedious, time-consuming and liable to error. Others require expensive apparatus or considerable skill, or tend to be operator dependent. Moreover, not only the mean diameter of a fibre sample is important, but also the distribution of diameter values. For this reason, much effort has been expended during the last decade to develop apparatus able to perform rapidly this measurement. Two such systems, based on optical methods, have been reported.

The major difficulty encountered in this problem lies in the fineness of the objects to be measured, which ranges between a few microns and one hundred microns for most textile fibres. The present invention relates to a system based on light diffraction, that performs a rapid, absolute and potentially automatic measurement of the diameter distribution of textile fibres or other fine wires. The method is self-calibrated; it does not require any comparison with a standard measured by other techniques. It also permits the measurement of finer fibers than does existing rapid automatic apparatus.

According to the present invention the small object, such as a textile fibre, is introduced into the path of a beam of coherent monochromatic light, and the resulting diffraction pattern is analysed to determine the diameter of the object.

The preferred apparatus according to the invention comprises a source of coherent monochromatic light, such as a laser, means for introducing small objects into the path of a beam of light from the source, means for producing an image of the diffraction pattern produced by the object and means for analysing the pattern to determine the diameter of the object.

The means for introducing small objects is preferably adapted to introduce rapidly a succession of the objects, more especially a succession of fibres or fragments thereof. It advantageously comprises a transparent conduit or optical cell, placed in the path of the beam, through which can be passed a suspension of fibre fragments or other objects in a liquid medium.

The measuring means preferably comprises an opto-electronic detector or transducer capable of

65 producing signals representative of the diffraction pattern formed by the object and means for computing the apparent diameter of the object from such pattern.

The invention will further be described, by way of example, with reference to the drawings, in which:

Fig. 1 illustrates a series of functions to be considered in analysing a diffraction pattern;

Fig. 2 is a diagrammatic representation of an apparatus embodying the invention;

Fig. 3 is a cross section through a modified form of cell for use in the apparatus of Fig. 2;

Fig. 4 is a cross-section on line IV—IV of Fig. 3;

Fig. 5 is a diagram of a fluid supply system for

80 the cell of Figs. 3 and 4; and

Figs. 6 and 7 illustrate the diffraction patterns and video signals obtainable with the cell of Figs. 3 and 4. Fig. 8 illustrates a modified beam trap and Figs. 9 and 10 illustrate a modified version of

85 the cell of Fig. 4.

The principle of measurement of the present invention lies in the production and analysis of the diffraction pattern formed when an object with a refractive index different from its surrounding 90 medium is placed in a beam of coherent monochromatic light.

It is well known that when a narrow object, hereinafter called the fibre, is placed in a beam of coherent light, such as a laser beam, whose 95 wavelength is shorter than the width of the object, a diffraction pattern can be observed on a screen placed in the forward direction with respect to the incident beam. This diffraction pattern is perpendicular to the fibre axis, 100 symmetrical around the beam axis, and shows successive maxima and minima at intervals related to the width of the diffracting fibre. As a general rule, the finer the fibre, the larger the spacing of the maxima and minima.

105 Depending on the distance between the diffracting fibre and the screen, the phenomenon is generally referred to as Fresnel diffraction or Fraunhofer diffraction. In the latter case, the diffraction pattern is fairly simple; except in the 110 very central region and provided that the distance from the centre is not too large, the intensity in the pattern behaves like

$$(\sin \alpha / \alpha)^2,$$

115 wherein  $\alpha$  is both proportional to the distance from the centre, and to the width of the fibre. Thus the minima are zeros and the distance between them is constant (except for the first minimum around the centre for which the distance is exactly double). For Fraunhofer

120 diffraction to be obtained, the distance between the fibre and the screen has to be very large (in principle infinite). However the same situation can be obtained at any finite distance by using an appropriate focusing lens. In that case, the

125 diffracting fibre is placed in front of the lens and the screen behind the lens, at a distance equal to the focal length. The distance  $\Delta$  between

successive minima is absolutely related to the fibre diameter  $d$  by the simple formula:

$$\Delta = F\lambda/d$$

where  $F$  is the focal length and  $\lambda$  the wavelength of the light. The measurement of  $\Delta$  thus gives immediately the value of  $d$ , provided that  $F$  and  $\lambda$  are known.

Both Fresnel and Fraunhofer diffraction can be used in the present invention, but the latter should be preferred for there are particular advantages in the design of an apparatus based on this principle. In the Fraunhofer case using a focusing lens, the positions and dimensions in the diffraction pattern do not depend on the distance between the fibre and the lens. They are also independent of an off-axis position of the fibre in the light beam. Hence when the fibre is brought into the light beam, the pattern appears, and remains identical even when the fibre is moving across the beam. It is thus possible to measure the diameter of a swiftly moving fibre by analysing the fixed diffraction pattern, provided that the orientation of the fibre does not change significantly while it crosses the beam.

In a rapid and automatic system of sample preparation as described below, it is unavoidable that the fibres should cross the light beam in nearly random orientation, causing the corresponding diffraction pattern to be also randomly oriented. Thus a particular system is provided by this invention to extract the significant information rapidly from a pattern, whatever its orientation. Its principle is to detect the 2-dimensional image containing the diffraction pattern by means of an opto-electronic transducer, to memorise this image electronically, to process it in order to extract from the memory the significant 1-dimensional information representing the diffraction pattern, and finally to analyse it.

The method of analysis of the now processed diffraction pattern is also particular to this invention. It is based on spectral analysis by means of a Fourier transform. In order to understand the operation, consider first an ideal function

$$(\sin \alpha / \alpha)^2$$

shown at 1 in Fig. 1. Its Fourier transform is a triangular function 2, with an edge frequency corresponding exactly to the period between the minima in the original function. On the other hand, if we compensate perfectly for the variation

$$(1/\alpha)^2$$

we are left with  $\sin^2 \alpha$ , which is equivalent to a  $\cos 2\alpha$  function plus a constant, as shown at 3.

Here the Fourier transform 4 will exhibit only one frequency corresponding again to the distance between the minima, plus the zero-frequency corresponding to the constant. In the

60 present example, an intermediate situation is reached by means of appropriate filtering devices consisting of a completely opaque central zone in order to remove the permanent central bright spot, and a radially varying continuous attenuation filter that roughly compensates for the

$$(1/\alpha)^2$$

variation for the range of fibre diameters to be measured. In this way the intensity in the diffraction pattern resembles somewhat a  $\sin^2 \alpha$  function, also with a central zero minimum, as at 5. Its Fourier transform 6 shows a zero-frequency peak and another peak frequency corresponding to the distance between the minima in the pattern.

The principle of the analysis of the extracted diffraction pattern produced by a fibre is thus to compute its Fourier transform and to locate in this the peak frequency which in turn is proportional 80 to the fibre diameter. Actually, the frequency scale obtained in the Fourier transform corresponds linearly to a fibre diameter scale.

One example of apparatus according to the invention, and its manner of operation, will now 85 be described with reference to Fig. 2, also by way of example only.

A sample preparation method has been designed to achieve a short measuring time and simple handling of the instrument. The purpose is 90 to pick up individual fibres from a sample of fibres and bring them one by one automatically across the light beam of the optical measuring system. A sample of the fibres to be measured consists of 10000—30000 fibres.

95 The preferred preparation comprises the following procedure. The fibres to be measured are cut into snippets about one millimetre long using a microtome. The snippets do not have to be exactly the same length, which enables a very

100 simple manual microtome to be used. The snippets are then poured into a vessel 7, where they are completely dispersed in a liquid 8 by means of a mixer 9. The liquid intended to carry the snippets has to fulfil several requirements: it must be clear and transparent, because it is traversed by the light beam; and it must not cause any swelling of the snippets, which would distort the diameter measurements. After the snippets have been dispersed, the liquid is allowed to flow

110 through a circulating system including a transparent conduit 10 which constitutes the measuring cell traversed by the light beam 11 as described below. After passing through this cell, the snippets are filtered out at 12, so that the

115 liquid is reusable and is recycled by a pump 13. The amount of liquid, the flow rate, the snippets concentration as also their length, the cross-sectional area and shape of the cell, its length and other parameters should be carefully chosen in such a way that most of the snippets travel individually through the cell, at a nearly constant speed, giving a relatively steady value for the rate

of snippets crossing the light beam. The cell may also be designed to decrease the turbulence of the flow. Though it is not a mandatory feature of the system, this will give a preferential orientation to the snippets when flowing through the cell.

In the preferred embodiment of the invention, based on Fraunhofer diffraction, the optical elements of the system are a laser light source 14, the measuring cell 10 and a focusing lens 15, together with filtering devices and a screen described below. The laser should be low-powered (several milliwatts), working in the TEM<sub>00</sub> mode, which gives the simplest distribution of intensity in the light beam. The measuring cell mentioned above is placed in the path of the laser beam. From the optical point of view, this cell has to be made of highly transparent material with two flat, parallel and highly polished windows between which the snippets flow. The internal distance between the parallel windows is preferably 1—2 mm.

The remaining optical elements are aligned on the beam axis. The focusing lens 15 is placed beyond the measuring cell. In order to remove the central bright spot from the pattern, the lens should have a beam trap 16 on its front side, consisting of a hollow cylinder with light absorbing bottom and walls. This system avoids problems caused by multiple reflections in the lens and protects the opto-electronic sensor (described below) against excessive illumination at its centre. The distance between the measuring cell and the lens is not critical but it determines the size of the central dark zone in the pattern, shadowed by the beam trap. It can thus be adjusted in order to obtain the best size for the central dark zone. The focal length of the lens depends on the dimension required for the pattern, but it also determines the length of the optical part of the apparatus. Typical focal length should be 20—40 cm. A screen 17 is placed at a distance from the lens equal to the focal length. It consists of a diffusing material, e.g. ground glass. A filter 18 is placed at its front side, showing continuously increasing transmittance as one moves away from the centre. For good mechanical stability to be achieved, all the optical components should be firmly fastened on a rigid base, preferably an optical bench, which allows for easy adjustment. Owing to the intensity of the laser light source, the system need not be operated in the dark, but a reduced light environment is desirable.

When the liquid circulating system carrying the fibres operates, a diffraction pattern 19 is formed for a while on the screen each time a snippet crosses the laser beam within the measuring cell. An opto-electronic transducer is used to convert the 2-dimensional image appearing on the screen into a time-varying signal (video signal). In a preferred embodiment of the invention, this opto-electronic transducer is a vidicon camera 20, but other types of camera may be considered provided that their sensitivity is sufficient. The standard vidicon camera has the advantages of low cost

and suitable sensitivity. In the preferred embodiment, the camera 20 is directed at the screen 17 through a suitable objective 21. In other embodiments, the camera target itself constitutes the screen where the pattern is formed. The first solution allows greater flexibility in setting optical parameters. Among others, an iris diaphragm can be used to adjust the amount of light reaching the camera target; the enlargement can be readily adjusted by varying the distance between the camera and the screen, in order to accommodate several measuring ranges. The second solution has the advantages of compactness and simplicity, and leads to a higher sensitivity since no light is dispersed by an intermediate screen.

When a camera is used, the 2-dimensional picture is represented by a video signal whose amplitude is proportional to the luminosity of the corresponding element of the image as it is scanned line-by-line. Owing to the dynamic range of the opto-electronic transducer, the range of variation of light intensity in the image should not be too large. This is accomplished by means of the filtering devices described above. The range of the camera is such that the

$$(1/\alpha)^2$$

intensity variation in the pattern could not be compensated in the video signal.

In the situation of this invention, the observed image is not permanent. The diffraction pattern appears merely as a flash on the camera target as a snippet crosses the laser beam. In most cases, the time a pattern exists on the screen is less than the time for the camera to scan its target. However the target has a storage capability ensuring that each image element remains on the target in the form of an electric charge until reached by the reading element of the camera (a scanning electron beam in the case of the vidicon). The local charges are then erased at the same time as a video signal proportional to them is produced. Taking this into account, when a pattern arises, its video representation appears at the output of the camera during one scanning period and then vanishes. It is very hard to carry out the calculation involved in the analysis process during this scanning period (typically 20 ms), and so some form of memorisation of the video signal is required. In a preferred embodiment of the invention, a digital video memory is used to store the 2-dimensional image of the pattern. This device converts in real time the outstanding video frame into a digital form and stores it in a large semiconductor memory array. Once the entire image is memorised, it becomes possible for electronic circuitry to detect the effective orientation of the pattern and to generate a 1-dimensional representation of it which consists of a set of digital values proportional to the luminosity of the diffraction pattern as seen by the camera.

Remembering that the picture information in

the memory is in digital form, the electronic circuitry required for extracting the 1-dimensional pattern is a digital system. In one possible embodiment of the invention, the system is a fast software-directed processing unit (a microprocessor or a microcontroller). In another embodiment of the invention, it is a hardware system specially designed to perform the task. In both cases, the pattern extraction must be done as fast as possible to ensure the highest analysis rate for the instrument. In particular the pattern extraction system should be able to perform the following operations:

- 1—detect the instant when a pattern image is stored in the memory;
- 2—stop the storage for the time required to perform the extraction;
- 3—test whether the stored image is actually a pattern corresponding to one fibre snippet or not.
- If the stored image corresponds to a dust particle rather than a snippet, it will show concentric rings or a diffused spot; if it corresponds to more than one snippet, it will show more than one characteristic pattern. On the other hand, for the pattern to be considered as extractable by the pattern extraction system, it should look like a bright line with some luminosity variations along its axis.
- 4—scan the stored picture along the axis of the pattern, once the above test is successfully passed, and to send out to an analysis process or the successive digital values corresponding to the pattern.
- 5—resume the storage mode until situation 1 occurs again.

The analysis processor receives diffraction pattern data in digital form and submits them to a spectrum analysis algorithm. In one possible embodiment of the invention, this analysis is performed by a digital software-directed computer. In another embodiment of the invention, the spectrum analyser is a hardware system. The time of analysis must be short, but there is no need for it to be shorter than the added times of complete video scan and pattern extraction, because the diffraction pattern data can be stored in an intermediate buffer inside or just before the spectrum analyser. With such an arrangement, the spectrum analyser processes the data from a diffraction pattern while the pattern extraction system may be processing the next diffraction pattern.

If both the pattern extraction system and the spectrum analyser are software-directed devices, they can be implemented in the same computer. In a preferred embodiment of the invention, the analysis algorithm based on a Fourier transform may be of the FFT type (Fast Fourier Transform). Furthermore, the spectrum analyser should be able to detect the peak value of the frequency spectrum excluding the zero-frequency peak. According to the above developments, the frequency corresponding to this peak value is absolutely proportional to the fibre diameter.

65 The last element involved in the apparatus is

the distribution analyser. Its purpose is to collect the diameter values as they are given by the spectrum analyser and to arrange them into convenient forms: for example, mean diameter, coefficient of variation, distribution histogram, cumulative distribution diagram or individual measured values. In a preferred embodiment of the invention, a digital computer performs these tasks. This computer can be the same as the one used for the already mentioned processing system.

A system according to the above embodiments of the invention should be able to measure fibre diameters between 3 and 150 micrometers, which may be divided into two ranges of setting. The system is rapid because it is able to measure 10000—30000 fibre diameters per hour. It is also automatic because an operator is only required for preparation of the fibre snippets, but not during the measurements.

The measurements performed with this system are absolute because the information picked up from the diffraction pattern is absolutely related to the fibre diameter by a straightforward physical law involving only length measurements, without reference to any other instrument.

An alternative form of measuring cell will now be described, the transparent conduit 10 being replaced by a more sophisticated device.

Referring to Figures 3 and 4, the liquid conveying the fibre snippets is conducted through a glass capillary 102 (dropping-tube), disposed coaxially in a second capillary 103 of the same type. The termination of the first capillary opens into the second one, in the region where the latter gets narrower. In the second capillary flows the same liquid as in the first one, but without snippets dispersed in it. In this way, as the flow from the first capillary flows into the second capillary, it is compressed and drawn by the surrounding liquid, thus forming an extremely narrow and laminar flow 105 in the core of the flow of the second capillary. This property remains unchanged well beyond the termination of the second capillary when the system is held vertically. The effect will be called hydrodynamic focalization. The liquid of the first capillary, conveying the snippets from the sample, will be referred to as the sample liquid, that one from the second capillary will be referred to as the focusing liquid.

The first consequence of the hydrodynamic focalization is that the snippets conveyed by the sample liquid are well localized inside the total flow (sample liquid + focusing liquid) along a very stable and narrow axis (typical values of 100—200  $\mu\text{m}$  diameter are obtained for the focused flow inside a capillary of 1—1.5 mm diameter).

125 Another important consequence is that elongated particles, such as fibre snippets, in the sample liquid are with their axis aligned along the flow axis when coming into the second capillary. Hence, when this system is embodied in the previously described apparatus, all the diffraction

patterns from the snippets will be perpendicular to the flow axis as this flow crosses the laser beam. This property allows for a drastic simplification in the image analysis because the orientation of all the relevant patterns is known.

However, the observation of the diffraction patterns is not directly possible with the system as it has just been described. Indeed, when the laser beam crosses the flow, either through the glass tube of the second capillary, or when it opens in the air, light reflected and refracted from the liquid flow or from the glass capillary scrambles the diffracted pattern.

For making easier the observation of the diffraction pattern, the measuring cell 101 has an additional part consisting of a conduit 106 in which flows a liquid identical to that one flowing in the second capillary. Thus the flow from the second capillary opens in the same liquid and all the three flows form a homogeneous medium that fills the conduit. The system as described, operates with the flow axis vertical. The conduit is bounded in a first horizontal direction by two flat walls 107 that come closer to each other as one moves from the top to the bottom of the cell. This particular profile limits the total flow at the output 108 of the cell and preserves the laminar flows beyond the termination of the second capillary. In a second horizontal direction, perpendicular to the first one, the conduit is bounded by two flat walls 110 parallel to each other. A part of these walls consists of two flat windows 111 of good optical quality (optical flats), through which the optical observation can be done. The liquid introduced in the conduit thus forms a sheath between the flow from the second capillary and the optical windows; therefore it will be referred to as the sheath liquid. In this way the narrow laser beam directed to the measuring cell traverses the first window and the homogeneous liquid medium, and crosses the aligned snippets swiftly flowing in this medium. The diffracted light is then observed through the second window.

It is to be observed that the speed of the snippets emerging from the second capillary is very high. Values of about 8 m/s are observed with the sample liquid focused down to 100  $\mu\text{m}$  diameter.

For the hydrodynamic focalization to occur and remain unaltered in the measuring cell, a precise balance of the pressures of the three liquids has to be achieved. This can be done with the hydraulic system sketched on Figure 5, by way of example.

The hydraulic system consists of two main circuits, one for the sample liquid and one for the focusing and the sheath liquids.

The first circuit comprises a vessel 112 filled with the liquid containing the snippets well dispersed by means of a mixer 113. This sample liquid is sucked up through a circuit by a pump 114 and is poured back 115 into the vessel via a constant head arrangement having a vertical tube 116 in which the sample liquid flows from bottom to top. The lower part 117 of this tube feeds the

first capillary of the measuring cell 101 while the upper part 118 opens to the air. The upper level of the sample liquid in the tube is at a constant height 119 and at atmospheric pressure. This in turn determines a constant pressure at the input of the first capillary in which a part of the sample liquid moves down by gravity.

The second circuit mainly supplies the focusing liquid and the sheath liquid. It consists of an upper vessel 120 filled at a constant level 121 with the liquid. Two tubes 122 in the bottom of the vessel 120 feed the measuring cell with the focusing liquid and the sheath liquid. Pressure control in the measuring cell can be achieved by means of valves 123 in the two tubes 122.

The total flow leaving the measuring cell is transmitted by a tube 124 into a lower vessel 125 then sucked up by a pump 126, passed through a filter 127 and poured back into the upper vessel 120. In order to keep a constant level in the latter, an overflow pipe 128 from this vessel pours down in the lower vessel.

In this way, the pressures of the three liquids in the measuring cell can be kept constant independently of the amount of liquid in the hydraulic circuit.

Due to the property of fibre alignment by hydrodynamic focalization, an important modification is also introduced in the electronics, in the way that we describe now:

As the fibre snippets are aligned vertically, all the corresponding patterns are horizontal. The orientation of the vidicon camera can thus be chosen such that the diffraction patterns be parallel to the scanning lines. In this way the light intensity distribution in a diffraction pattern can be found directly by looking at the video signal corresponding to the relevant lines.

However, diffraction patterns can appear that are not aligned horizontally or that have not the characteristic linear shape. These cases occur when snippets are too much curved causing a misalignment, or when two snippets are twisted round each other, or when non-fibrous particles

are present in the liquid (dust, impurities). In order to reject these irrelevant images, the video memory is provided with an additional device (see Figures 5 and 6). It consists of an electronic circuit that allows to select two rectangular zones

129 in the 2-dimensional image 130 from the camera. The positions and the dimensions of these rectangles can be adjusted in order to centre them around the well aligned diffraction patterns 131. On the other hand the image read

120 on the camera target is converted into video signals, digitized and stored in the memory where it stays for one scanning period and is then replaced by the next image. However, when the light intensity within any one of the rectangles is

125 such that the corresponding video signal 132 exceeds a given threshold 133, a circuit is enabled which stops the storage process at the end of the current image scan and the whole image is kept in the memory. The threshold level 133 is adjustable in order to discriminate the patterns from the

background. The pattern extraction method is thus greatly simplified compared to the previous one. The image kept in the memory in digital form shows the characteristic horizontal pattern 131 extending on a few lines. The pattern extraction system then takes the average signal by summing up the several lines where the pattern extends. The number of lines in the sum is also adjustable. The average signal is then submitted to the spectrum analysis algorithm and the storage mode of the memory is resumed.

Finally, an improvement can also be made to the optical system. Owing to the fact that the relevant patterns are aligned horizontally, a more effective beam trap can be used which is independent of the focusing lens and held on a vertical support. Such an arrangement is sketched on Figure 8 by way of example. It consists of a small mirror 134 fixed on a 45° tilted part of a support 135. The horizontal incoming laser beam is directed onto the mirror, then reflects vertically and penetrates a horn-shaped glass tube 136 fixed at the top of the support 135. This glass tube is preferably black painted outside, thus the laser beam is completely lost inside it by successive internal reflection. The main advantage of this system is that it can be moved along the laser beam axis independently of the focusing lens and can be placed either between the measuring cell and the lens, or between the lens and the observation screen. In this way a great flexibility in the choice of the size of the central dark zone on the screen is obtained.

Various models of measuring cells can be used to obtain the hydrodynamic focalization. As an example a very simple model of such a cell different from that described above is now described with reference to Figs. 9 and 10. It consists mainly of a bar 137 from high quality optical glass with flat faces and with a conduit 138 of square or rectangular cross section in its centre (as seen in Fig. 10 which is a plan view of the cell with the tube 142 omitted). A typical size for the section of this conduit is 2x2mm. In the upper part of the cell is a chamber 139 of circular cross section which is fed with pure liquid by a lateral tube 140. The transition region 141 between the chamber 139 and the conduit 138 may be of conical shape. A dropping tube 142 with a capillary 143 is fitted to the upper part of the chamber 139 in such a way that the end of the capillary 143 opens in the transition region 141. The sample liquid containing the snippets is flowing through the upper tube 142. When a suitable balance of the pressure in this tube and in the chamber 139 is achieved, hydrodynamic focalization occurs in the transition region 141 and the focused flow remains stable and laminar within the conduit 138. The focusing liquid coming from the tube 140 thus surrounds the sample flow in the flat walls conduit. Compared to the above described focusing cell, in the present configuration the liquid from the tube 140 serves both as focusing liquid and sheath liquid. The laser beam then crosses the cell 137 and the

conduit 138 perpendicular to the flow axis. The present system is thus simpler than the previous ones because the focusing cell configuration is much less sophisticated and only two liquid flows are required rather than three. The regulation of the pressures of these liquids can be achieved by a circuit similar to that one used with the previous cell. A limitation of the flow in the opening 144 of the conduit 138 has however to be performed, for example by a counter-pressure device.

It may be noted that the alignment of the fibres by hydrodynamic focalization is effective only if the curvature of the snippets is not excessive. Hence, in the case of curled fibres, the snippets have to be cut short enough to reduce the curvature. On the other hand they have not to be too short, for the alignment effect works only on elongate particles. A compromise has thus to be found depending on the nature of the fibres to be measured. Typical optimal length is a few hundred microns. For this preparation it is necessary to use a more elaborate microtome than that required in the case of the first-described embodiment of the invention.

Although in this specification and in the claims which follow, reference has been made to 'light', it will be apparent that forms of electromagnetic radiation other than the visible spectrum may be employed for the purposes of the invention, in association with appropriate sensors, and the term 'light' should be construed accordingly throughout.

#### Claims

1. A method of measuring the diameter of small objects of substantially circular cross-section, comprising conveying the object across the path of a beam of monochromatic light to produce a diffraction pattern, the transient pattern formed as an object passes the beam being detected by an opto-electronic transducer, electronically stored and analysed to determine the diameter of the object.
2. A method according to claim 1 in which the diffraction pattern, projected on a screen, is detected by the opto-electronic transducer and analysed electronically.
3. A method according to claim 2 in which a rapid succession of small objects is carried through the beam and successive individual diffraction patterns produced thereby are detected, stored and analysed sequentially.
4. A method according to claim 3 in which the small objects are conveyed in a transparent liquid medium which is passed through a cell placed in the path of the beam.
5. A method according to claim 4 in which the 2-dimensional image of a linear diffraction pattern of a randomly oriented object is detected and stored in digital form, and is analysed to detect the orientation of the pattern and to generate a signal affording a 1-dimensional representation of the pattern.
6. A method according to any preceding claim in which the analysis of the diffraction pattern or

of a signal representing the diffraction pattern is performed by a Fourier transform method.

7. A method according to any preceding claim in which the  $(1/\alpha)^2$  variation of the diffraction pattern is reduced by means of a radially varying continuous attenuation filter.

8. A method according to any preceding claim in which the permanent central bright spot in the pattern is removed by means of a beam trap located on a Fraunhofer diffraction forming lens.

9. A method according to any preceding claim in which the diameter measuring range is altered by positional adjustment of the optical elements employed.

10. Apparatus for measuring the diameter of small objects of substantially circular cross-section, comprising a source of monochromatic light, means for conveying an object across the path of a beam from the source, an opto-electronic transducer for receiving a diffraction pattern formed by the object to produce electrical signals, and memory means for storing the signals.

11. Apparatus according to claim 10 in which the light source is a laser.

12. Apparatus according to claim 10 or 11 in which the means for producing an image comprises a lens forming a Fraunhofer diffraction pattern in its focal plane.

13. Apparatus according to claim 12 including means, for example a beam trap, for eliminating the central zone of the pattern.

14. Apparatus according to claim 12 or 13 in which the means for producing an image also includes a radially varing continuous attenuation filter.

15. Apparatus according to any of claims 10 to 14 in which the memory means comprises a digital video memory for storing a succession of signals from the opto-electronic transducer representative of a succession of patterns produced by individual objects introduced successively into the path of the beam.

16. Apparatus according to claim 15 including means for analysing the pattern stored in the video memory.

17. Apparatus according to claim 16 in which the analysing means is a digital computer.

18. Apparatus according to any of claims 10 to 17 in which at least one optical element is adjustable to vary the range of diameters to be measured.

19. Apparatus according to any of claims 10 to 18 in which the conveying means comprises a transparent conduit in the path of the beam adapted for passage of a liquid medium with the object in suspension.

20. Apparatus according to claim 19 in which the conveying means comprises means for producing a first stream of liquid containing the object and means for producing a second flow of liquid surrounding the first so as to effect a constriction of the first stream.

21. Apparatus for measuring the diameter of small objects of substantially circular cross-section, comprising a source of monochromatic light, means for conveying an object, suspended in a stream of liquid, across the path of a beam from the source, and means for analysing the resulting diffraction pattern, in which the conveying means comprises means for producing a first stream of liquid containing the objects and means for producing a second flow of liquid surrounding the first so as to effect a constriction of the first stream.

22. Apparatus according to claim 20 or 21 in which the combined flow is arranged to pass through a conduit of square or rectangular cross-section.

23. Apparatus according to claim 20 or 21 in which the conveying means includes means for producing a third flow of liquid surrounding the second.

24. A method according to claim 1 substantially as hereinbefore described with reference to the accompanying drawings.

25. Apparatus for measuring the diameter of small objects substantially as hereinbefore described with reference to the accompanying drawings.

26. A method of measuring the diameter of small objects, for example textile fibres, in which the object is introduced into the path of a beam of coherent monochromatic light and the resulting diffraction pattern is analysed to determine the diameter of the object.

27. Apparatus for measuring the diameter of small objects, for example textile fibres, comprising a source of coherent monochromatic light, means for introducing an object into the path of a beam from the source, means for producing an image of the diffraction pattern formed by the object, and means for analysing the image to determine the diameter of the object therefrom.